

## HERMETIC ENCAPSULATION TECHNIQUE FOR SOLAR ARRAYS

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### ABSTRACT

A concept is presented for encapsulating solar cells between two layers of glass either individually, in panels, or in a continuous process. The concept yields an integral unit that is hermetically sealed and that is tolerant to high temperature thermal cycling and to particulate radiation.

Data are presented on both high temperature solar cells and special glasses that soften at low temperatures for use with the concept. The results of encapsulating experiments are presented which show the successful application of the concept to the special high temperature cells. The mechanical feasibility of encapsulating 2 mil cells between two layers of 2 mil glass is also demonstrated.

### INTRODUCTION

The desirability of an integral bond between solar cells and cover glasses has long been recognized. Such a bond would eliminate the need for UV rejection filters and would increase the resistance of the stack to thermal transients and thermal shock. Early efforts were motivated by requirements for deep space probes and array hardening against nuclear weapons environments. More recent motivation comes from three basic areas, 1) the need for arrays that are hardened against thermal transients induced by laser weapons, 2) the need for arrays that can be thermally annealed in space in order to increase mission life in radiation environments, and 3) the need for low-cost, high reliability encapsulating techniques for terrestrial arrays.

The earlier attempts at making integrally bonded cell-cover glass stacks utilized such techniques as sputtering (ref. 1) of glass layers onto the cells. To date, these processes have been too time consuming to be economical. They also resulted in excessive shear stresses at the interface between the cell and the glass. A more recent process has been the use of electrostatic field-assisted bonding techniques (ESB) (refs. 2, 3, 4) for sealing the glass to the solar cell. This process is still under development and shows promise. Indeed some of the glasses being developed for the present concept may also prove useful for the ESB process.

The present concept offers an alternative for an adhesiveless structure that is applicable to individual cell processing and also to low-cost automated continuous process fabrication.

### Concept Description (ref. 5)

The process starts with rolling a sheet of glass out of a glass melting tank as is commonly done in the glass industry. A top roller forms indentations having the dimensions of the solar cells to be encapsulated. The cells are then deposited into the indentations when the glass is just below the softening temperature. The solar cells are interconnected at this point by a metal foil or by spraying interconnectors in a liquid metal form similar to computer printer techniques. The second sheet of glass which is at a higher temperature and, hence, has a lower viscosity is then rolled on to the array. This completes the encapsulation. The process is illustrated in figure 1. Where metal foils are used for the interconnects the pressure of the glass laminations is sufficient to press the contacts into electrical contact. The nature of the hermetic seal prevents corrosion and degradation of these contacts.

The first attempts at demonstrating this encapsulation technique were performed in an inert atmosphere using 7740 borosilicate glass between graphite dies at a temperature of 750°C for 15 minutes and 1 psi contact pressure. These parameters yield a close fitting interface as shown in figure 2.

The mechanical feasibility of the process has been demonstrated for both thick and thin solar cells. Figure 3 shows a 2-mil thick cell encapsulated between two sheets of 2-mil thick 7740 borosilicate glass.

However, it is well known that conventional solar cells degrade rapidly at temperatures in excess of 450 to 500°C. Thus, for the present concept it is desirable to have a radiation resistant glass that closely matches the thermal expansion coefficient of silicon which softens at a temperature lower than that of commercial borosilicate glasses. These borosilicate glasses can be formulated to closely match the thermal expansion coefficient of silicon. However, these low expansion coefficient glasses have a relatively high softening point temperature ( $\sim 800^\circ\text{C}$ ). While it appears that the process would be most efficient at a rolling speed of about 2 meters per second resulting in each cell being at the encapsulating temperature less than one minute, this time-temperature combination still severely degrades conventional cells. Thus, it was concluded that work should be done to develop improved glasses and solar cells for the process.

### High Temperature Cell Development (ref. 6)

Boeing electronics has developed a proprietary process (ref. 6) for fabricating concentrator solar cells using a mesa type contact structure that reduces the series resistance and increases the thermal resistance of the cells. These cells have been encapsulated by the above process and survived a 15 minute soak at a temperature of 750°C with only minimal degradation of the final electrical parameters. Figure 4 shows the electrical characteristics of these cells before and after encapsulation. A number of these cells have been successfully encapsulated in Corning Code 7740 (Pyrex) glass.

This cell fabrication concept is currently being extended to space type 1 sun (AMO) cells; however, the results are not available at this time.

## Glass Development

In order to avoid excessive shear stress at the glass-solar cell interface the thermal expansion coefficient of the glass must closely match that of the solar cell. For silicon cells the expansion coefficient is about  $4 \times 10^{-6}$  cm/cm°C. The glasses of borosilicate composition can be formulated to match silicon very closely. During this effort five different borosilicate glasses have been examined (Corning Code 7050, 7070, 7720, 7740, and 3320). These glasses were fabricated into 2-mil thick microsheet on a glass blower's lathe by blowing a large diameter cylinder from 30 mm glass tubing. This yielded very uniform microsheet with a slight curvature which could be flattened due to its flexibility as illustrated in figure 5. The encapsulating experiments were performed using the microsheet between two high density graphite dies. The graphite dies were separated by blocks of soda lime glass which softened at a lower temperature than the borosilicate glasses. This prevented the microsheet from being crushed initially and allowed the dies to be slowly forced together as the temperature increased and the borosilicate glass softened to the point that it would not crack under the  $\sim 1$  psi pressure of the dies.

Another constraint on the glass is that it must be radiation resistant. For the borosilicate glasses this leads toward the selection of a low alkali content glass such as Corning Code 7070; however, this glass is approximately 26 percent boron oxide and tends to undergo phase separation when heated to the softening temperature for a significant length of time.

Two additional types of borosilicate glass formulated by Schott Glass Company, Schott 8250 and Schott 8330 were doped with ceria in hopes of increasing their radiation tolerance; however, it was found that they darkened severely after the ceria doping so that no further experiments were performed on them.

The soda-lime microsheet doped with Cerium Oxide is in use successfully for discrete solar cell covers in space, but cannot be used for integral encapsulation because the thermal expansion coefficient is too high. However, there is a family of glasses based on phosphorous pentoxide as a glass former rather than silicon dioxide. These phosphate glasses are not being used extensively for terrestrial applications because they are to some extent soluble in water. For space applications this is not a problem. Phosphate glasses are a good host for many oxides and are used for laser glasses. A glass of phosphate composition matching the coefficient of silicon and doped with  $\sim 3$  percent ceria has been melted and did not show any appreciable loss of light transmission after being irradiated to a fluence of  $\sim 4.0 \times 10^{15}$  proton per cm<sup>2</sup> at 1.5 MeV as shown in figure 6.

Since this ceria doped phosphate glass meets the thermal expansion requirements, is radiation tolerant, does not undergo phase separation at high temperature and promises a lower softening temperature than borosilicate glass, it appears to be an excellent candidate for the encapsulating process discussed herein. It is also being investigated as a candidate for electrostatic field-assisted bonding.

## CONCLUSIONS

In conclusion, a process for heremetically encapsulating solar cells either individually, in panels, or in a continuous process has been demonstrated. The mechanical feasibility of the process for extremely thin array-cell fabrication has been demonstrated and significant progress has been made in the development of solar cell fabrication techniques and glasses uniquely suited for the process has been shown. The encapsulation process promises arrays of good reliability, light-weight, and low cost since automation is readily applicable.

## REFERENCES

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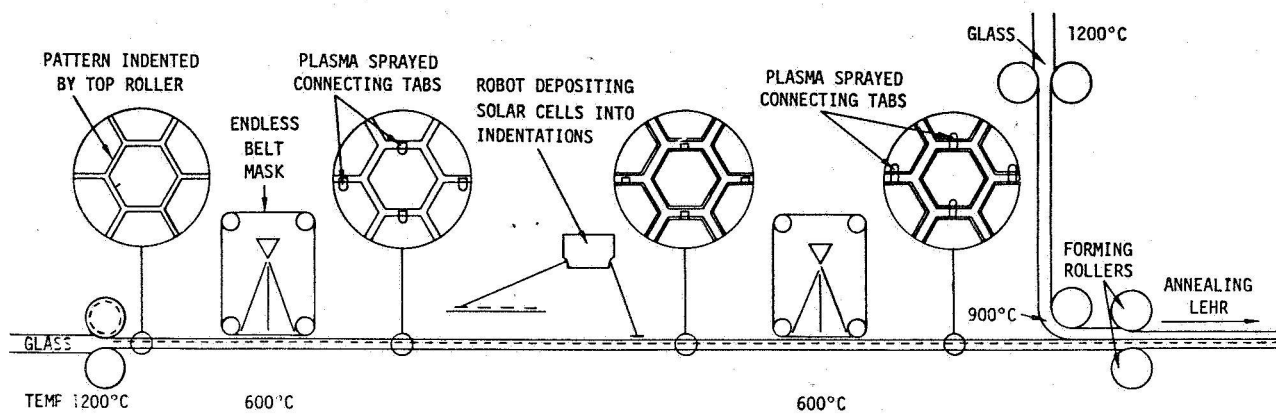


FIGURE 1. METHOD OF FABRICATING GLASS ENCAPSULATED SILICON SOLAR CELL ARRAYS

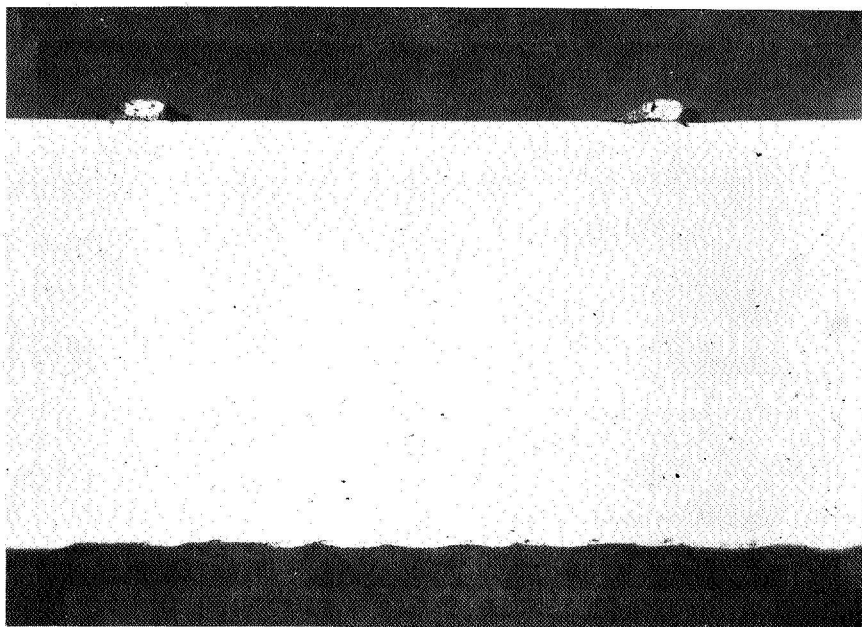


FIGURE 2. ILLUSTRATION OF GLASS CONFORMATION TO SILICON AND CONTACT SURFACES

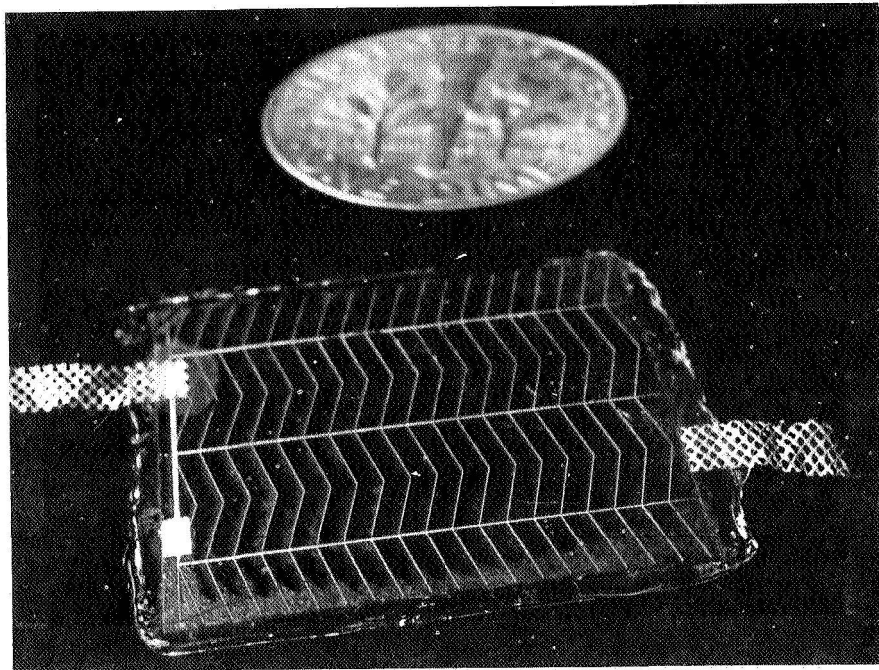


FIGURE 3. 2-MIL CELL ENCAPSULATED IN 2-MIL GLASS FRONT AND BACK

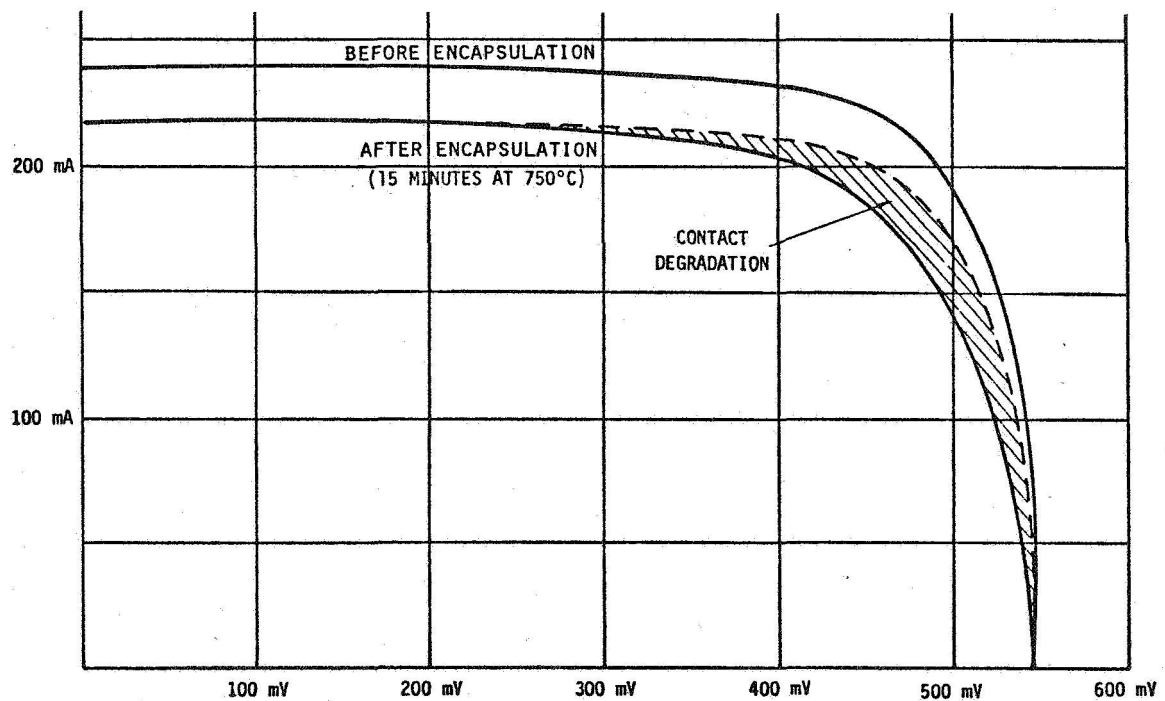


FIGURE 4. PERFORMANCE OF HIGH TEMPERATURE SOLAR CELLS

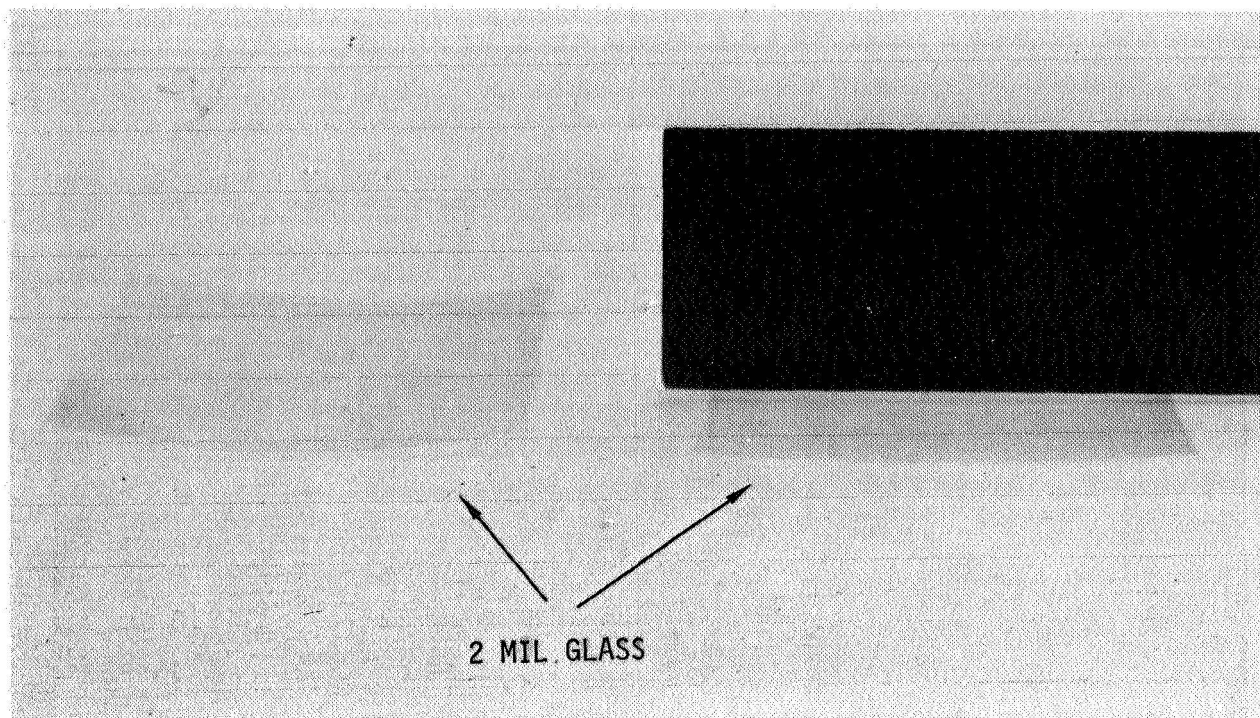


FIGURE 5. DEMONSTRATION OF 2 MIL 7070 BOROSILICATE MICROSHEET FLEXIBILITY

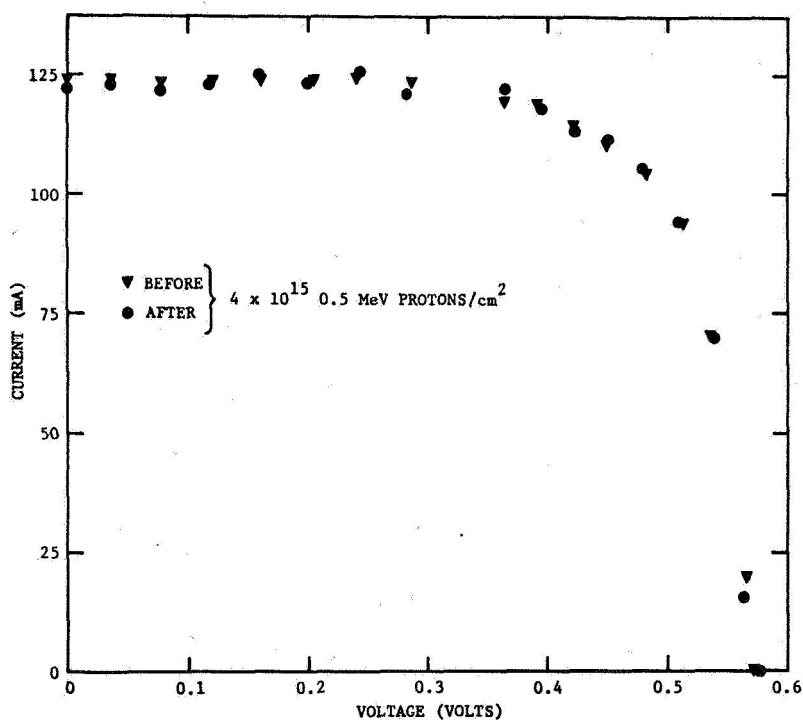


FIGURE 6. RESPONSE OF SOLAR CELL COVERED WITH CERIA-DOPED PHOSPHATE GLASS BEFORE AND AFTER IRRADIATION